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COMPUTATIONAL ANALYSIS OF THE BEHAVIOR OF ATMOSPHERIC POLLUTION DUE TO DEMOGRAPHIC, STRUCTURAL FACTORS, VEHICULAR FLOW AND COMMERCE ACTIVITIES

SUÁREZ G.[1], NIÑO J.A.[2], CHAKIR R.[3], HOYOS J.D.[1,2] AND STREICHENBERGER B.[3]

[1] Grupo de investigación en Matemáticas (GMAT), Escuela de Ingeniería
Universidad Pontificia Bolivariana, Cir.1 #70-01, 050031 Medellín, Colombia,
gustavo.suarez@upb.edu.co, www.upb.edu.co

[2] Grupo de Aeronáutica y Aeroespacial, Escuela de Ingeniería
Universidad Pontificia Bolivariana, Cir.1 #70-01, 050031 Medellín, Colombia, www.upb.edu.co
juliana.nino@upb.edu.co, www.upb.edu.co

[3] Laboratoire Instrumentation, Simulation et Informatique Scientifique (LISIS)
Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR), 14-20 bd Newton, Francia
rachida.chakir@ifsttar.fr, www.ifsttar.fr/accueil/

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Abstract. According to the latest assessments made by the world health organization (WHO-2016), the atmospheric pollution (air), has become one of the main causes of morbidity and mortality in the world, with a steep growth of respiratory diseases, increase in lung cancer, ocular complications, and dermis diseases [1,2,3]. Currently, there are governments which still underestimate investments in environmental care, turning their countries into only consumers and predators of the ecosystem [1,2,3]. Worldwide, several cities have been implementing different regional strategies to decrease environmental pollution, however, these actions have not been effective enough and significant indices of contamination and emergency declarations persist [1,2,3]. Medellín is one of the cities most affected by polluting gases in Latin America due to the high growth of construction sector, high vehicular flow, increase in commerce, besides a little assertive planting trees system, among other reasons [1,2,3]. With the purpose of providing new researching elements which benefit the improvement of air quality in the cities of the world, it is pretended to mathematically model and computationally implement the behavior of the flow of air, e.g., in zones in the city of Medellín to determine the extent of pollution by tightness, impact of current architectural designs, vehicular transport, high commerce flow, and confinement in the public transport system. The simulations allowed to identify spotlights of particulate tightness caused by architectural designs of the city which do not benefit air flow. Also, recirculating gases were observed in different zones of the city. This research can offer greater knowledge around the incidence of pollution generated by structures and architecture. Likewise, these studies can contribute to a better urban, structural and ecological reordering in cities, the implementation

of an assertive arborization system, and the possibility to orientate effective strategies over cleaning (purification) and contaminant extracting systems.

1 INTRODUCTION

In this research, a study was conducted on the dispersion of environmental pollution in several areas of the city of Medellín where there is a high traffic flow, commercial activities, high population density, among other incident factors. The city of Medellín has presented critical environmental conditions that are detrimental to the health of the population, especially in certain periods of the year where air flow is significantly reduced [4,5,6,7].

Medellín is in the region of the Aburrá Valley, composed by a extensive mountainous system, with high demographic density. Another component that has contributed to the accumulation of toxic particulate matter within the city, is the growing development of the construction sector that has not considered the incidence of structural designs (sizes and shapes) in the accumulation of toxic particles. [4,5,6,7].

In order to represent the behavior of air flow, a mathematical-computational model was developed including the detection of the level of particles, the effects of recirculation of the flow, the sealing of the particles by zones, buoyancy of particulate material, between obtained results. A three-dimensional model was elaborated with the structural elements and the urban distribution that make up the city. Conditions such as velocities of the air flow entering the city of Medellín were considered, along the borders of the bored valley, the direction of the wind, velocity profile, sources of gas emission, among others.

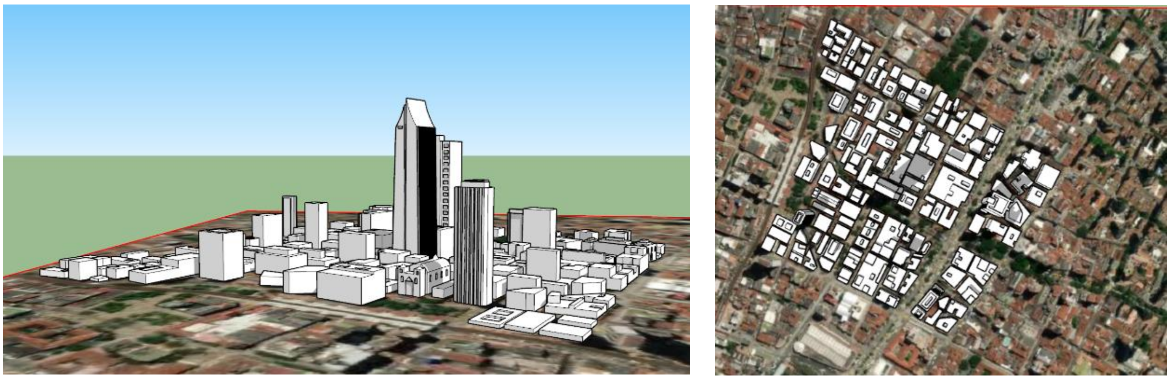
The main area where the regions were included for the analysis was established by a surface area of 700m^2. Data and previous studies of METEOBLUE, IDEAM (Institute of Hydrology, Meteorology and Environmental Studies) and SIATA (Early Warning System of Medellín and Aburrá Valley) were collected and analyzed. [4,5,6,7].

(a) (b)

Figure 1: Aburrá Valley (a) and pollution in the central zone of the city (b).

2 SYSTEM FUNCTIONALITY CONDITIONS

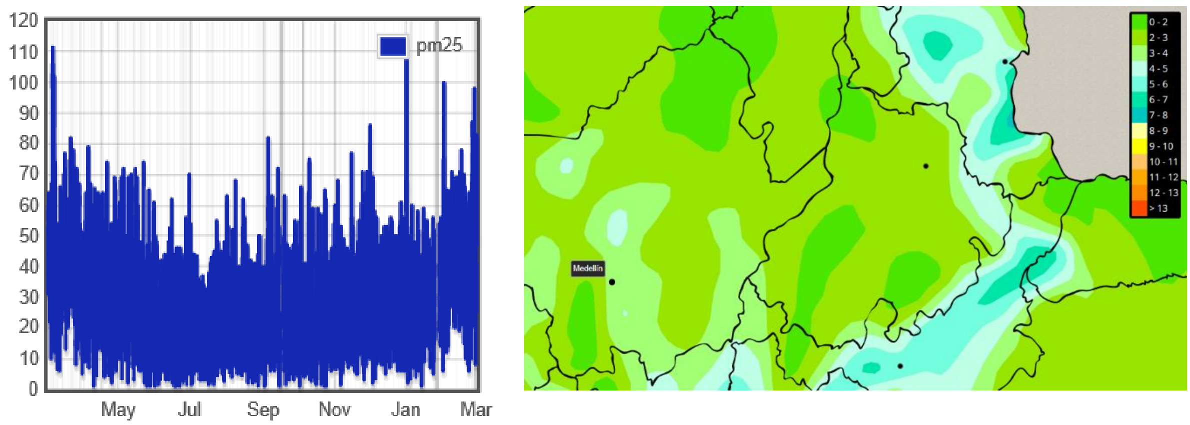
The central zone of the city of Medellín has been chosen for the high automotive, commercial and population flow in it, among other aspects. The structures of the buildings were developed using satellite images and perspectives of the region [8].



(a) (b)

Figure 2: Modeling of the central zone of the city of Medellín, panoramic view (a), aerial view (b).

The inlet conditions of the flows from the Aburrá Valley to the city of Medellín were determined. The levels of pm 2.5 are known for their adverse effects on human health, for this reason they are monitored by the municipal authorities. The SIATA has statistics of the increase of these particles, where it is observed that in July it is the month with the lowest concentration of pm 2.5, while March is the month with the highest concentration, fig. 3 [9,10].

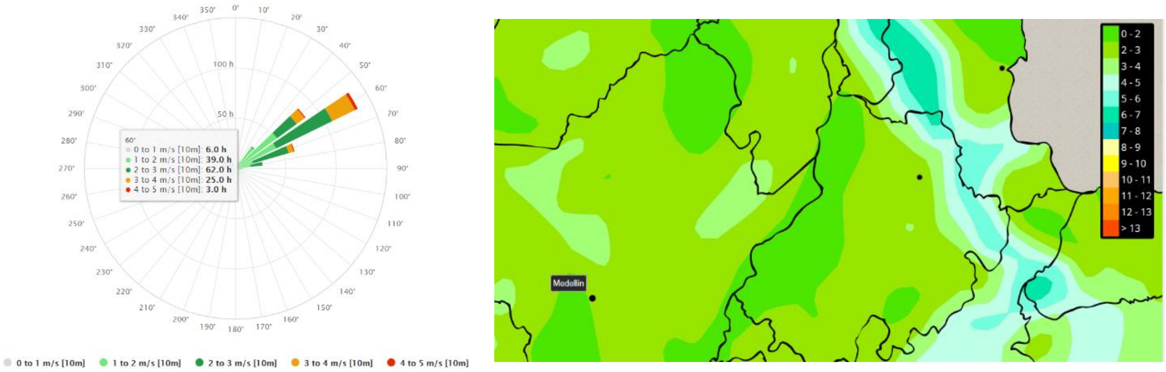


(a) (b)

Figure 3: Levels of pm2.5 in the center of Medellín (a) and wind speed in month of July (b).

It is possible to obtain the wind intensity map for each month of the year from the IDEAM data source. The map showing a higher average wind speed is the month of July with an average of between 3 and 4 m/s at a height of 10m that corresponds to the month with the lowest concentration of pm 2.5 [10,11,12].

According to this relationship, the most desirable scenario to develop the computational model, was the one with the highest concentration of particulate material and lower wind flow velocity. In this way, the acquisition of data from the METEOBLUE global climate database was develop with sampling days between March 11 and 25, 2019 at a height of 10m and 80m, fig. 4 [10,11,12].



(a) (b)

Figure 4: Compass rose 10 m above ground (a) and wind speed in month of March (b).

From the information obtained from METEOBLUE, it was found that the central value of the distribution is 2.3258 m/s at a height of 10m. This data is validated with the map provided by the IDEAM for the month of March in which a speed of between 2 and 3 m/s is observed. The data collection is made on the same date but at 80 m height, obtaining the average value of the distribution of 3 m/s. Once obtained these data, we proceed to modeling the change of speed with height, the power law is used for this purpose commonly [13].

$$U_2 = U_1 \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{1}$$

Where U_2 and U_1 are the wind speeds at heights h_2 and h_1 respectively, and α the roughness index. From the data obtained from METEOBLUE for 10m and 80m, $\alpha = 0.12237$ is found. The wind entry conditions, namely, the profile of speeds at the inlet and the wind direction of 50° given the wind roses obtained from METEOBLUE, was determined.

$$U(h) = 1.755h^{0.12237} \tag{2}$$

3 MATHEMATICAL MODEL

The turbulence model κ-ε, described below, was established for the development of the flow [14]:

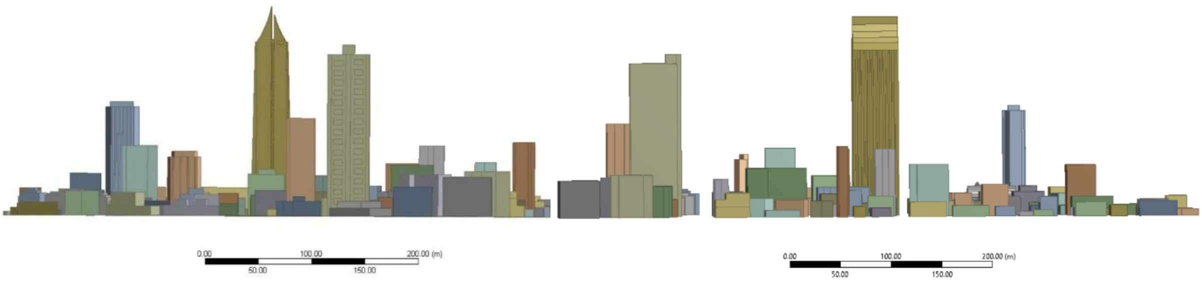
$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial}{\partial x_i}(\rho\epsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial\epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}(G_k+C_{3\epsilon}G_b)-C_{2\epsilon}\rho\frac{\epsilon^2}{k} \quad (4)$$

Where k is defined as the kinetic energy of the turbulent flow, ϵ is the turbulence dissipation rate, ρ is the density, t time, x_i y x_j are the are the Cartesian coordinates, μ_i is the flow speed, μ is the kinetic viscosity, G_k the turbulence production parameter, G_b is the kinetic turbulence energy generated by buoyancy, σ_κ and σ_ϵ are the turbulence coefficients.

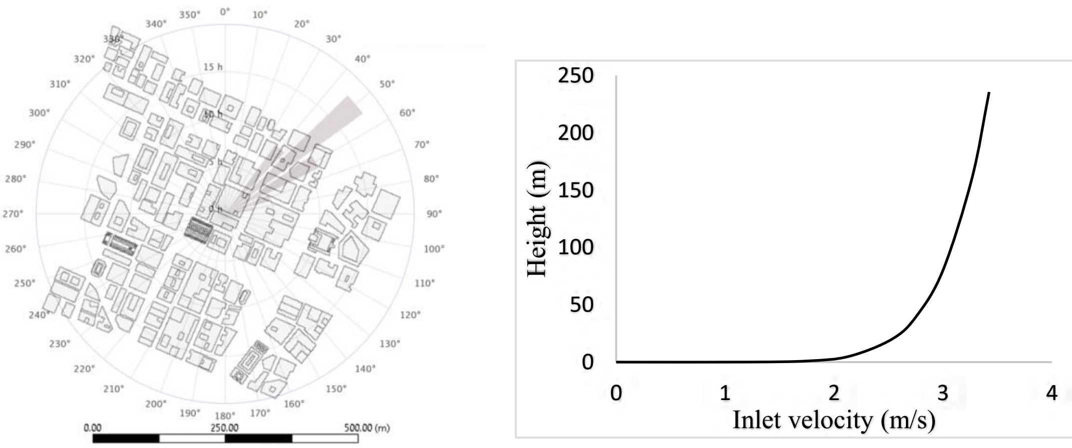
4 COMPUTATIONAL IMPLEMENTATIONS

The three-dimensional architecture of the chosen area of the city of Medellín was built, consisting of several sectors where behavioral studies were carried out. The different orientations of the flow that occur in the city due to the unevenness of the surface were considered [15].



(a) (b)

Figure 5: Architecture model of the chosen area in Medellín, front view (a) and side view (b).



(a) (b)

Figure 6: Wind direction of the area (a) and velocity profile at the inlet (b).

It was implemented as a condition for the inlet of the flow in the Aburrá Valley towards the city by means of the elaboration of a velocity profile provided from the data collection.

A grid with tetrahedral elements was elaborated for a total of 8'017.235 with a controlled refinement in the areas where the flow was considered to develop with greater speed, it would present turbulence, or also where it was required to evaluate the behavior of the particulate material, fig. 7.

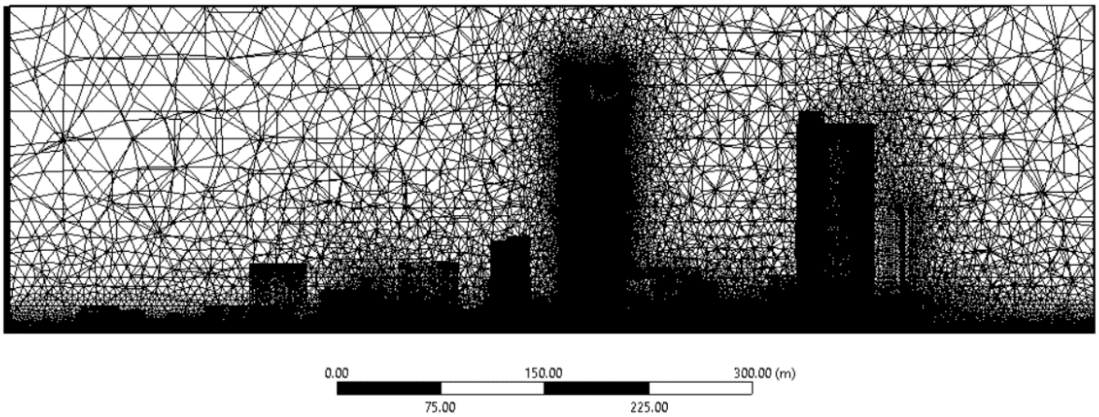
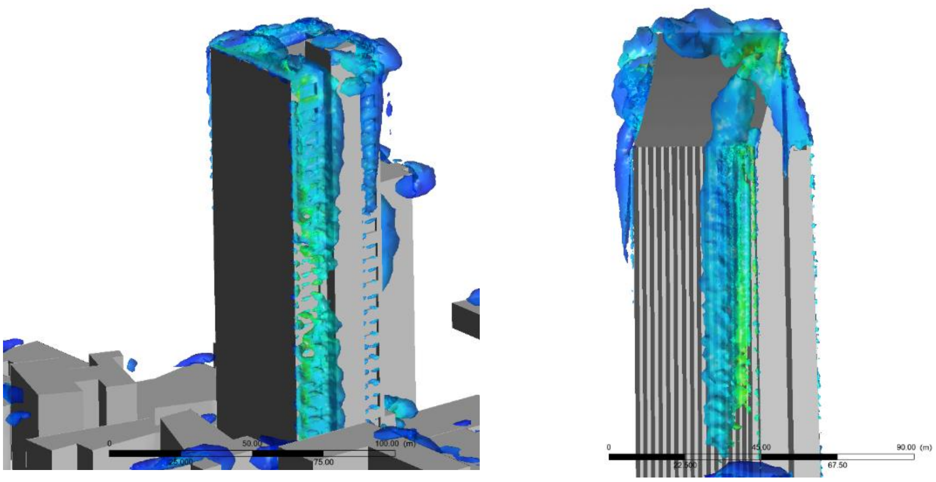


Figure 7: Development of the numerical grid for the volume where fluid behavior was studied within the city.

5 ANALYSIS AND RESULTS

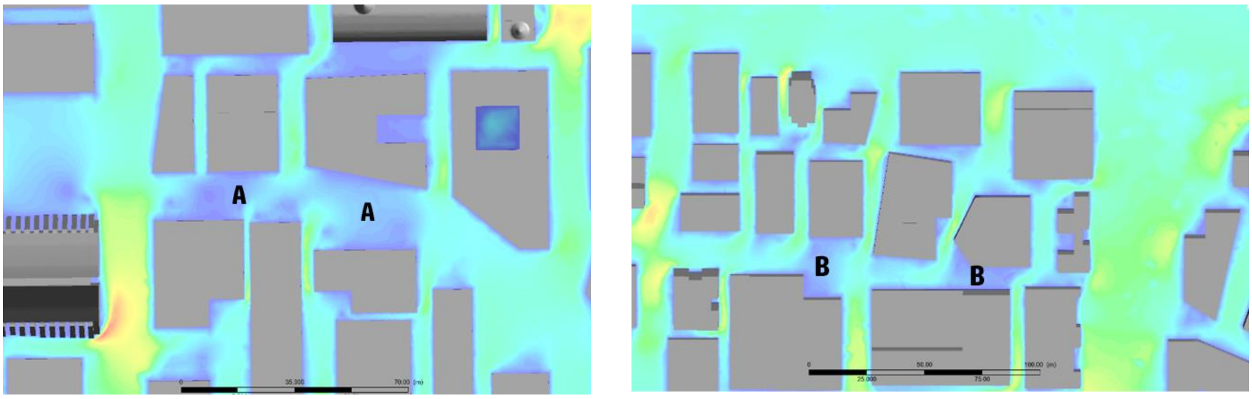
The results have indicated a significant turbulence due to the variability of the architecture in height and sizes and a possible accumulation of contaminating particles in some points of these structures due to recirculation effects. The results are presented below, especially in the *Cámara de Comercio* building and the *Coltejer* building. This behavior is evident in the slenderest buildings.



(a) (b)

Figure 8: Simulations of turbulence behavior at specific points and spotlights with recirculation. *Cámara de Comercio* building: Cl. 53 #45 (a), *Coltejer* building: Cl. 52 #42 (b).

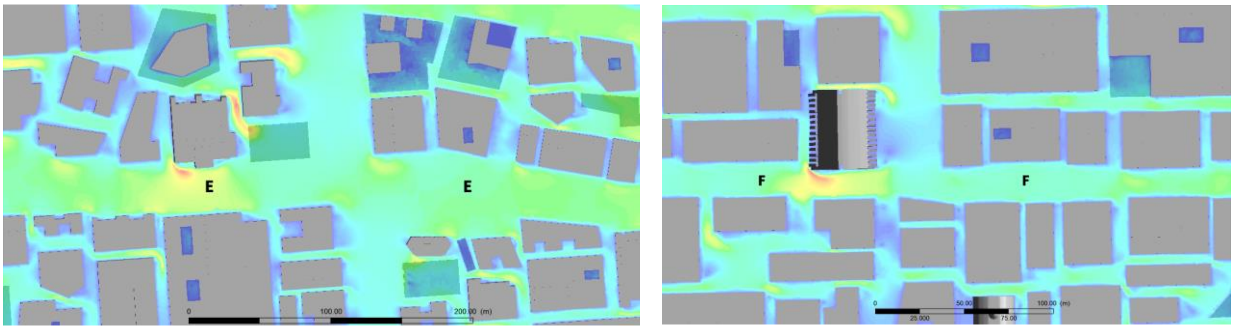
Below are some points of accumulation of particulate material where you can also observe sealing points where the air velocity is close to zero. This behavior would not allow polluting emissions to flow and spread. Some streets have an appropriate air circulation (yellow) while it is visible in different points of stagnation (dark blue), as shown in the fig. 9.



(a) (b)

Figure 9: Computational simulations of flow behavior. Aerial view of the area of the city with stagnation areas Cl. 52 # 50 (A) of the sector (a), and zone Cl. 54 # 47 (B) of the sector (b).

Otherwise, streets that have greater air circulation are shown in fig. 10. Medellín city is composed of narrow and wide streets without a certain order. This irregular urban condition caused a combination in stagnation effects and appropriate circulation in nearby analysis sites.



(a) (b)

Figure 10: High flow areas in Cra 46 *Oriental* Avenue (E), sector (a) and Cra 49 *Junín* Avenue (F), sector (b).

6 CONCLUSIONS

A study of the behavior of air flow in a large area of the city of Medellín was presented. Stagnation areas, turbulence, and recirculation were found, among other elements that contributed to the high contamination index.

It was shown that architecture and its forms hinder air circulation. It was also observed that even when there is a period of high air flow in the city, there are factors such as urban distribution, street dimensions (Cl. 52 # 50, and Cl. 54 # 47) which would not allow the effective dispersion of polluting gases in certain focused areas of the city. The largest recirculation and turbulence were found in the slenderest buildings. The streets Cra 46 *Oriental* Avenue (E) and Cra 49 Junín Avenue presented appropriate flow circulation.

Through the results of this research, it is expected to obtain a greater understanding of the impact of the effects that are polluting the city of Medellín, including demographic, chronological, structural factors, in addition, the traditional effects such as: the effects of automotive flow, population effects, and commercial among other factors included.

Based on the results, effective solutions can be provided in the future to reduce environmental pollution problems in the city of Medellín and its region.

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